



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

### **A MARKOV MODEL FOR MARINE CORPS ACQUISITION FORCE PLANNING**

by

Chris L. Nicholson

June 2012

Thesis Advisor:  
Second Reader:

Chad W. Seagren  
Bill Hatch

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**A MARKOV MODEL FOR MARINE CORPS ACQUISITION  
FORCE PLANNING**

Chris L. Nicholson  
Major, United States Marine Corps  
B.S., Georgia Institute of Technology, 2000

Submitted in partial fulfillment of the  
requirements for the degree of

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June 2012**

Author: Chris L. Nicholson

Approved by: Chad W. Seagren  
Thesis Advisor

Bill Hatch  
Second Reader

Bill Gates  
Dean, Graduate School of Business and Public Policy

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## **ABSTRACT**

This research is in response to a request by the Marine Aviation Detachment at Naval Air Station Patuxent River, MD. Currently, no manpower planning tools exist for force shaping of the Marine Corps Acquisition Community. This thesis creates a force shaping and forecasting tool for Marine Corps manpower planners. The tool assists planners in forecasting inventory levels across rank and Military Occupational Specialty combinations and in determining the most robust force structure for the acquisition officer community. Validation of the model reveals the usefulness of the planning tool for forecasting inventory levels, but it also indicates weakness in force structure analysis. This weakness is due to the small size and nascency of the current community; further data collection is required to validate the model for future use in force structure development.

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## LIST OF ACRONYMS AND ABBREVIATIONS

AMOS	Additional Military Occupational Specialty
ASR	Authorized Strength Report
DAWIA	Defense Acquisition Workforce Improvement Act
DACM	Defense Acquisition Corps Membership
DAU	Defense Acquisition University
DoD	Department of Defense
FY	Fiscal Year
GAR	Grade Adjusted Recapitulation Report
HRDP	Human Resource Development Process
MOS	Military Occupational Specialty
PM	Program Management or Manager
PMOS	Primary Military Occupational Specialty
SSN	Social Security Number
T2P2	Trainees, Transients, Patients, and Prisoners
TFDW	Total Force Data Warehouse
TO	Table of Organization
TOECR	Table of Organization and Equipment Change Request

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## **I. INTRODUCTION**

### **A. PURPOSE**

The current and projected fiscal environments will place enormous pressure on the Marine Corps and the Marine Corps acquisition budget. While the Marine Corps Acquisition Community represents only a small portion of the Marine Corps, the community disproportionately affects the performance, cost, and schedule of systems. Therefore, Acquisition Community's force structure directly impacts the Marine Corps both now and, more importantly, in the future.

Currently, the Acquisition Community may not be operating most efficiently. Few tools exist to aid Marine Corps manpower planners in shaping the Acquisition Community. The primary purpose of this research is to create a tool for Marine Corps manpower planners to shape the Acquisition force structure and forecast future inventory levels of the community.

The research analyzes the Marine Corps Acquisition Community defined as those officers with the Additional Military Occupational Specialty (AMOS) of 8057 or 8058 or the Primary Military Occupational Specialty (PMOS) of 8059. Officers with these AMOSs or PMOS with the rank of Captain through Colonel comprise the data set analyzed. This research explores the systemic behavior within the Acquisition Community in terms of accession, transition, and attrition and will answer the following research question:

**1. Would a markov model provide an accurate forecasting tool for inventory levels of the Marine Corps Acquisition Community?**

### **B. BACKGROUND**

The Defense Acquisition Workforce Improvement Act (DAWIA), enacted in November 1990 professionalized the Department of Defense (DoD) acquisition workforce. DAWIA mandated that military and civilian acquisition workforce members become certified. According to the Defense Acquisition University:

The Defense Acquisition Workforce Improvement Act (DAWIA) required the Department of Defense (DoD) to establish a process through which persons in the acquisition workforce would be recognized as having achieved professional status. Certification is the procedure through which a military service or DoD Component determines that an employee meets the education, training, and experience standards required for a career level in any acquisition, technology, and logistics career field. (2012)

Each service was then required to adhere to DoD standards of professionalism, but was left to manage their acquisition officers as they saw fit. The Marine Corps has largely left accession into, continuation and transition within, and attrition from the Acquisition Community up to the self-selection of each individual Marine. Seeking a more controlled approach, the Marine Corps created a PMOS for those Marines who achieved Defense Acquisition Corps Membership (DACM) and chose to pursue acquisition as a PMOS. In 2004, the Marine Corps established the 8059 PMOS for professional acquisition officers (Morgan, 2004).

In the years following the creation of the 8059 PMOS, the community has been ramping up to fill out the force structure. The complexity of the community (15 disparate DACM specialties and two AMOSs) coupled with the nascency of the community created a dearth of manpower planning tools. The results of this study will help to close that analytical gap.

### **C. SCOPE AND METHODOLOGY**

This study examines the systematic behavior within the Marine Corps Acquisition Community using markov modeling techniques. The scope of this study consists of Marine officers from Captain (O-3) through Colonel (O-6) with the AMOSs of 8057/9957 and 8058/9958 and the PMOS of 8059/9959 from October 2005 until December 2011. The aggregate data from the Marine Corps Total Force Data Warehouse (TFDW) for each of these individuals populate the probabilistic representations of transition, continuation, and attrition within the Acquisition Community.

### **D. ORGANIZATION OF STUDY**

The first chapter focuses on the overall purpose of the study along with a brief description of the background, scope and methodology, and organization of study. The

second chapter provides a detailed review of literature germane to manpower modeling of the Marine Corps Acquisition Community. The third chapter gives an in depth background of the Acquisition Community in general and the Marine Corps Acquisition Community specifically. The fourth chapter explains the data and methodology used in creating a markov model of the behavior of the Marine Corps Acquisition Community. This chapter gives the results and limitations of the model as well. The final chapter summarizes the study and provides conclusions and recommendations for each of the two research questions found originally in the first chapter.

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## **II. LITERATURE REVIEW**

### **A. PRIOR RESEARCH**

Prior to describing the background of the Acquisition Community and the methodology, this study explores some of the previous research on manpower planning. Significant research has been accomplished in the past regarding manpower planning for civilian firms, but research on manpower planning within the military deals primarily with larger populations such as officers in general or enlisted specialties. No research was found that has focused specifically upon the behavior of Marine Corps acquisition officers. This thesis attempts to fill that gap.

### **B. VAJDA (1978)**

Vajda's book, *Mathematics of Manpower Planning*, discusses the underlying theory of planning in the manpower environment. In fact, the author works through "high school mathematics" in describing manpower planning tools which include differential equations and matrix theory (Vajda, 1978, p. vii). While the mathematics may be slightly more complicated than Vajda intimates, the book provides a good introduction to quantitative manpower planning.

Vajda dismisses previous models (such as the "Kent Model") before listing the markov model as the "main tool" for manpower planning. This conclusion is based upon a series of proofs Vajda details in Chapter II in which he describes the use of markov modeling in "hierarchical" matrices (1978, p. 33). The use of markov chains in manpower planning is further reinforced by the work of Bartholomew, Forbes, and McClean.

### **C. BARTHOLOMEW, FORBES, AND MCCLEAN (1991)**

Bartholomew et al. provide an excellent overview of manpower planning tools in the second edition of their book *Statistical Techniques for Manpower Planning*. The seminal work of Bartholomew et al. gives, "a sound basis of technical knowledge for the manpower planning professional" (1991, p. xi). The basic terminology and notation used in this study are derived from Bartholomew et al.

In order to apply statistical techniques to manpower problems, Bartholomew et al. make two basic assumptions about behavior with a manpower system. First, any manpower system can be examined through archival data, and the data derived from archival study aggregates to provide a useful description of the system. Secondly, these aggregates can then be represented by probabilities which reflect the “uncertainty inherent in the social and economic environment in which the firm operates and from the unpredictability of human behavior” (Bartholomew et al., 1991, p. 1). These two assumptions allow for statistical techniques to be applied to manpower systems.

According to Bartholomew et al. each model for a manpower system then must provide a “mathematical description” of behavior with regards to constraints to the system and flows within the system (1991, p. 6). Marine acquisition professionals are constrained by the number of billets available for the PMOS of 8059. Therefore, the system cannot generate more individual 8059s than there are billets. The flow of the system describes how individuals move through the system. Some of these flow behaviors are controlled (changing to the PMOS of 8059 requires a board) and some are not (such as voluntary retirement). Constraints and flows are common to all manpower models.

Bartholomew et al. recommend using “transition models based on the Theory of Markov Chains” when dealing with “heterogeneous systems in which people are classified according to such things as grade, age, or location” (1991, p. 95). These markov chains lend themselves nicely to the study of military systems in which individuals exist within mutually exclusive states such as Military Occupational Specialty (MOS) and rank. In fact, Bartholomew et al. specifically mention how markov chains answer basic questions about “ideal” force structure (1991, p. 96).

#### **D. OTHER CIVILIAN STUDIES**

The use of markov models in civilian manpower planning is both prodigious in scale and widely varied in the population studied. Journals are replete with articles discussing the mechanics of markov modeling in general application to manpower planning (Blakely, 1970; Davies, 1973; Davies, 1981; Nilakantan, Sankaran, &

Raghavendra, 2011; Sales, 1971; Wijngaard, 1983). For specific populations, markov modeling has been applied to the management of graduate students (M. G. Nicholls, 2009; 2007), firefighters (Fry, Magazine, & Rao, 2006), and even clerical staffing (Mould, 1996). The large volume of work and wide variety of subjects reveal the robust nature of using markov modeling in manpower planning applications.

#### **E. MILITARY STUDIES**

Within the military, the use of markov models for manpower planning is pervasive and also ranges across many different population types. On a general scale, the military application of markov chains includes the management of Army reserve enlisted (Ginther, 2006), Coast Guard enlisted (Fiebrandt, 1993), Marine Corps first term enlisted (Nguyen, 1997), Navy Unrestricted Line Officers (Weber, 1980), and even Indonesian Army officers (Suryadi, 1990). On a smaller, more specific scale, markov models have been applied to planning military subpopulations such as the Navy Seals (Hooper, 2011), Navy Medical Service Corps (Butler, 1990), Navy Nurses (Kinstler & Johnson, 2005), Navy AEGIS Fire Controlmen (McKeon, 2007), and many others. Military applications range across topics from broad categories to small groups, but no work has been done on the Acquisition Community in general or Marine Corps acquisition officers specifically.

#### **F. CHAPTER SUMMARY**

The use of the markov chain for evaluating the behavior of manpower systems has been well established both in civilian firms and within the military, but no research was found to have focused upon the Marine Corps Acquisition Community. Bartholomew et al serve as the basis for applying a markov chain to the Acquisition Community. The markov model answers the primary research questions of this study.

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### III. BACKGROUND

#### A. DEPARTMENT OF DEFENSE ACQUISITION WORKFORCE REQUIREMENTS

The Defense Workforce Improvement Act (DAWIA) requires every acquisition professional to meet minimum standards in education, training, and experience. Defense Acquisition Corps Membership (DACM) is granted across 15 subspecialties. Each of those subspecialties has different requirements for education, training, and experience (Defense Acquisition University, 2012). The individual services must then manage their own force structures and the career paths of their acquisition professionals.

The detailed requirements for DACM under the Program Management (PM) track are shown in Figure 1. In order to achieve DACM as under the PM track, the acquisition professional requires four years of experience (waiverable to three if the individual has received a master's degree in an approved business related program) and training through the Defense Acquisition University (DAU). Once the individual has attained level 3 status, then they may apply for DACM.

**DAWIA Career Field Certification Requirements Matrix**  
(as of 2/11/2011 - see DAU Catalog for current requirements)

Career Field	Cert. Level	Education Requirement	Experience	Course Number	Course Length	Delivery Method
LCL	3	Not Required	4 Years	LOG 350	9 Days**	Classroom
				Two CL Modules	Variable	Web
PM	1	Not Required	1 Year	ACQ 101	25 Hours	Web
				SYS 101	35 Hours	Web
				CLB 007	3.5 Hours	Web
				CLB 016	1 Hour	Web
PM	2	Not Required	2 Years	ACQ 201A	37 Hours	Web
				ACQ 201B	5 Days	Classroom
				PMT 251	50 Hours	Web
				PMT 256	30 Hours	Web-Facilitated
				CON 110	23 Hours	Web
				IRM 101 or SAM 101	35 Hours	Web
PM	3	Not Required	4 Years	PMT 352A	50 Hours	Web
				PMT 352B	22 Days	Classroom
				SYS 202	30 Hours	Web

Figure 1. Program Management DAWIA Career Field Certification Requirements Matrix (from Defense Acquisition University, 2012)

## B. MARINE CORPS HUMAN RESOURCE DEVELOPMENT PROCESS

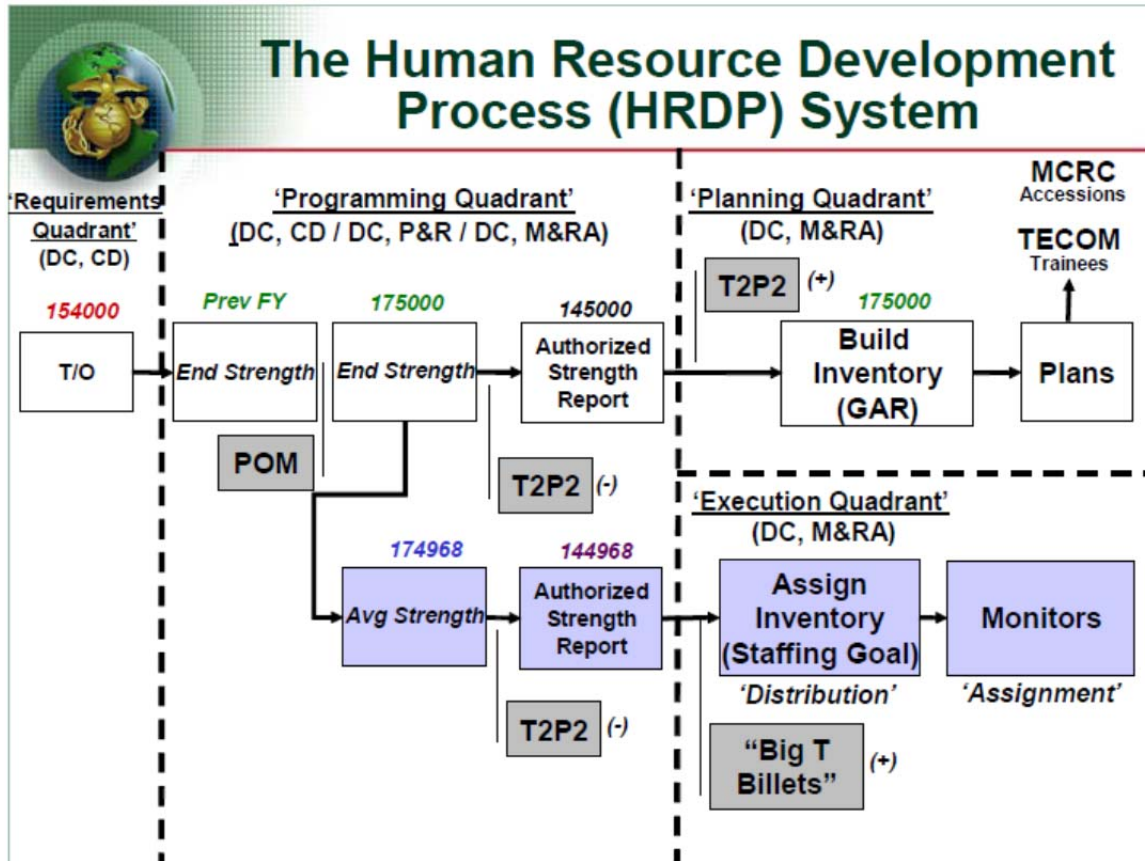


Figure 2. The HRDP System (From Barry & Gillikin, 2005)

Barry and Gillikin (2005) distill the Marine Corps Human Resource Development Process (HRDP) into an understandable format in their in-depth thesis. Barry et al. state that the mission of the HRDP is, “to ensure both the operational commanders and the supporting establishment have the Marines required to accomplish their numerous tasks,” and further describe the HRDP in terms of four quadrants: Requirements, Programming, Planning, and Execution (Barry & Gillikin, 2005). We use their model (see Figure 2) to briefly discuss the Marine Corps HRDP as it relates to acquisition officers, but a more in depth discussion can be found in Barry et al’s thesis.

## **1. Requirements**

In the requirements phase, Marine Corps manpower planners take inputs from the Acquisition Community for changes to the Table of Organization (TO). The needs of the Acquisition Community are weighed and balanced against the needs of other communities and of the needs of the Corps as a whole. Manpower planners then synthesize the requests of all communities within the Marine Corps in producing the TO (Barry et al., 2005).

## **2. Programming**

The programming phase translates the wish list of the TO through the reality of the budget. The TO is then compared with the previous year's end strength in order to produce an average end strength. After subtracting those Marines unavailable for assignment (Trainees, Transients, Patients, and Prisoners or T2P2), the Authorized Strength Report (ASR) is produced. The ASR then provides the input for the next two of the four phases (Barry et al., 2005).

## **3. Planning and Execution**

The ASR then moves into the Planning and Execution quadrants simultaneously. The planning quadrant transforms the ASR into a structured inventory called the Grade Adjusted Recapitulation Report (GAR) which describes how many of each rank should exist within each MOS. The execution quadrant uses the actual Marines assignable to fill the billets delineated by the planning quadrant. In the end, the Acquisition Community must have both a billet from the planning phase and a Marine available from the execution phase in order to accomplish its mission (Barry et al., 2005).

## **4. Officer Promotions**

The Marine Corps differs from the other services in promoting officers. As all Marine officers are expected to be qualified to lead Marines into combat, Marine officers compete across MOS so that the very best officers may be promoted. Officers with AMOSs must remain relevant to both their PMOS and AMOS simultaneously in order to

be competitive for promotion. The requirement to compete against all officers regardless of MOS means that managing small, disparate MOS communities like acquisition officers is challenging.

### C. MARINE CORPS ACQUISITION MILITARY OCCUPATIONAL SPECIALTIES

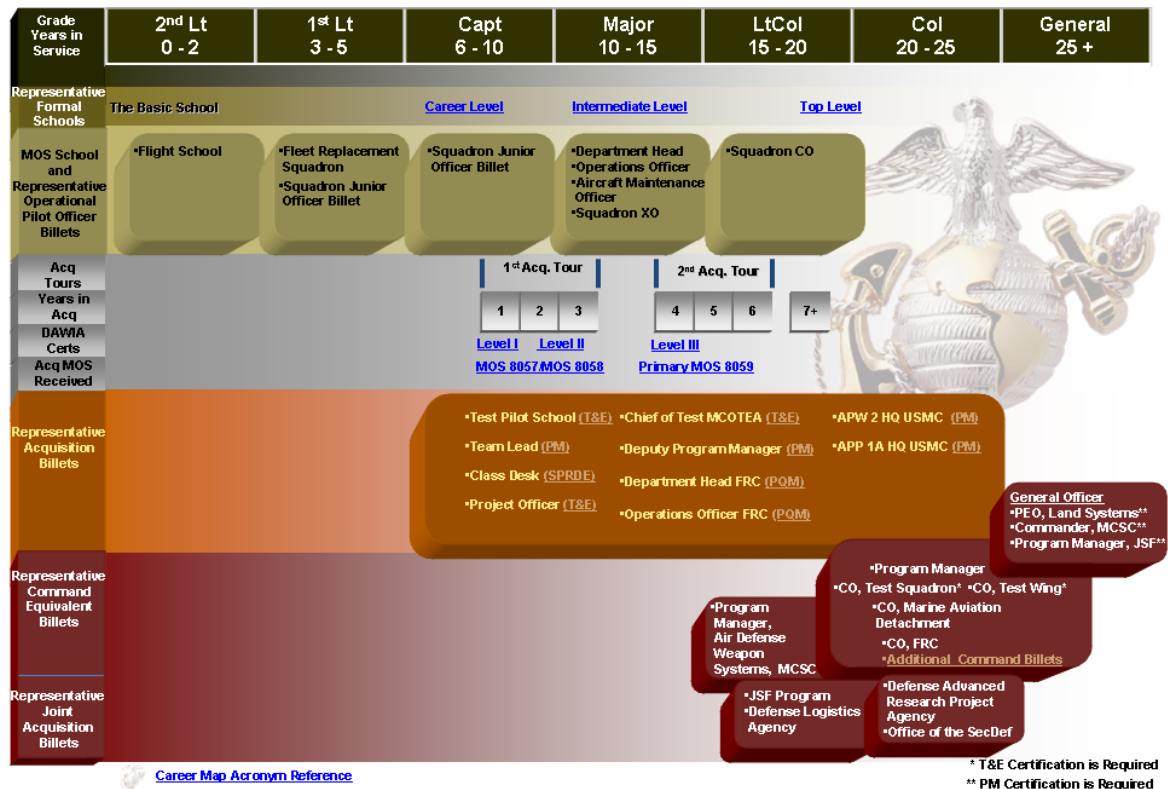


Figure 3. Typical Career Progression for a Marine Aviation Acquisition Officer  
(From Expeditionary Warfare School, 2005)

In 2004, the Marine Corps announced the intent to establish a PMOS of 8059 to more closely manage Marine acquisition officers. Additionally, the AMOSs of 8057 and 8058 were also created to denote the progression of officers in the acquisition field, but who are not yet acquisition officers in PMOS. Figure 3 depicts a typical career path for an acquisition professional with an aviation background. These three MOSs and the ranks within comprise the focus of this study.

**1. 8057**

Marine officers with the AMOS of 8057 must possess: a baccalaureate degree, have a minimum 24 semester hours in business, and must receive a level 2 certification in an acquisition career field that requires two years of experience (MCO 1200.17C, 2008). These officers self-select into billets that provide the two years of experience, voluntarily complete the training and education requirements, and then submit for their level 2 certification. The Acquisition Community has little control over these officers other than the number and type of billets that provide 8057 experience.

**2. 8058**

Marine officers with the AMOS of 8058 must: be a major or higher, have a baccalaureate degree, have a minimum 24 semester hours in business, possess a secret security clearance, have a level 2 certification in an acquisition career field, have four years of experience (three if they have master's degrees in an approved business related program), and have DACM (MCO 1200.17C, 2008). Officers with an 8058 AMOS possess all of the prerequisites for the 8059 PMOS, but have not yet voluntarily applied to become professional acquisition officers.

**3. 8059**

Marine officers with the PMOS of 8059 must meet all of the requirements of the 8058 AMOS and must also voluntarily apply to and be accepted by the Marine Corps Career Acquisition Management Board (MCO 1200.17C, 2008). Officers with an 8059 PMOS now focus solely upon acquisitions and incur a four year additional obligation upon acceptance of the new PMOS. Marine Corps manpower planners actively manage the number of 8059 officers selected and the promotion rate of 8059 officers, but cannot control how many officers apply.

**D. CURRENT FORCE PLANNING TOOLS**

Currently, Marine Corps manpower planners have few tools for managing the Acquisition Community. Essentially, manpower planners can control the number and type of billets through the TO, determine the number of 8059s accessed each year by the

Marine Corps Career Acquisition Management Board, and influence the promotion rates of those officers with the PMOS of 8059. Self-selection into the community and voluntary transition with the community determine a large part of the shape of the force structure, but are outside of the control of manpower planners.

On a day to day basis, manpower planners track the current inventory of 8059 officers at each grade via a spreadsheet. The current inventory is then compared to the target inventory (90% of T2P2). The target inventory is managed via Table of Organization and Equipment Change Requests (TOECR) submitted once per year. The inventory of 8057 and 8058 officers are not tracked or managed in any way. By only tracking current 8059 inventory, Acquisition Community managers remain purely reactive and lack a holistic view of the community.

#### **E. CHAPTER SUMMARY**

The DAWIA caused the DoD to professionalize its acquisition corps, while leaving the management of those professionals to each individual service. The Marine Corps has created a career field in which Marine officers self-select into and voluntarily advance within the Acquisition Community through the AMOSs of 8057 and 8058 to the PMOS of 8059. Current tools available to planners notably lack forecasting and a holistic view of the community. Understanding the behavior of officers within the Marine Corps Acquisition Community is therefore essential for effective planning and control.

## **IV. DATA, METHODOLOGY, AND RESULTS**

### **A. INTRODUCTION**

This chapter describes the data used for the study, the methodology applied, and the results of the model.

### **B. DATA**

The data for this research was downloaded from the Marine Corps Total Force Data Warehouse (TFDW). TFDW contains the administrative data from all Marines including demographic information (race, sex, age, etc.) and military information (gas mask size, physical fitness scores, PMOS, AMOS, rank, years of service, etc.). The following variables were downloaded from TFDW for Fiscal Year (FY) 2005 through 2011:

#### **1. Sequence Number**

The sequence number provides a numerical equivalent to the month of the data snapshot, i.e., 200=October 2005.

#### **2. Social Security Number**

The Social Security Number (SSN) provides a means of identifying individuals within the data. For privacy reasons, SSNs were replaced by an identification number through a mathematical transformation.

#### **3. Rank**

The data contains ranks from Captain (O-3) through Colonel (O-6), and were the focus of the study. The variable rank has only four possible values (3 through 6 representing Captain O-3 through Colonel O-6).

#### 4. MOS

The MOS variable captures in numeric format the PMOS and AMOS of each Marine. The MOS variable was distilled so that only individuals with acquisition MOSs remained. The MOS variable contains three possible values (57 through 59 representing 8057 through 8059).

#### 5. Rank MOS

The Rank MOS variable is a concatenation of Rank and MOS. Because Captains cannot attain the AMOS of 8058 or the PMOS of 8059, Rank MOS has ten possible values (3 57, 4 57, 4 58, 4 59, 5 57, 5 58, 5 59, 6 57, 6 58, and 6 59 representing Captain O-3s with the AMOS of 8057 through Colonel O-6s with the PMOS of 8059).

#### 6. Summary Statistics

##### a. Rank MOS Totals by FY

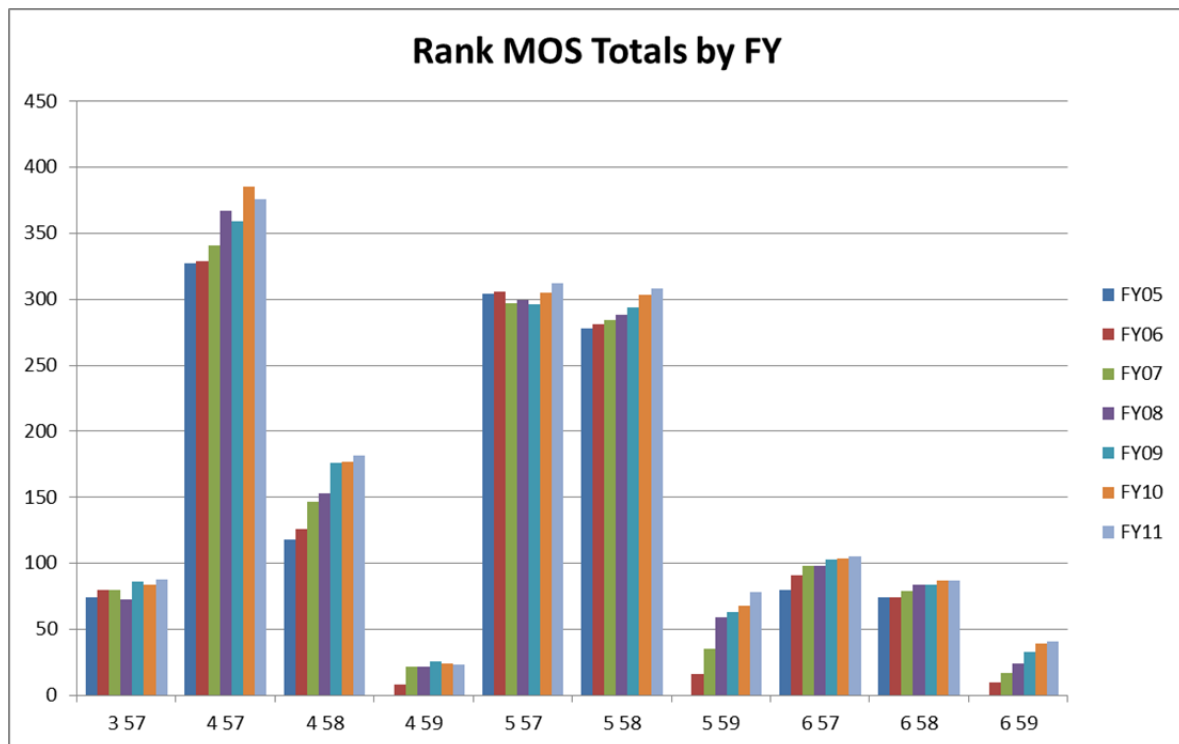
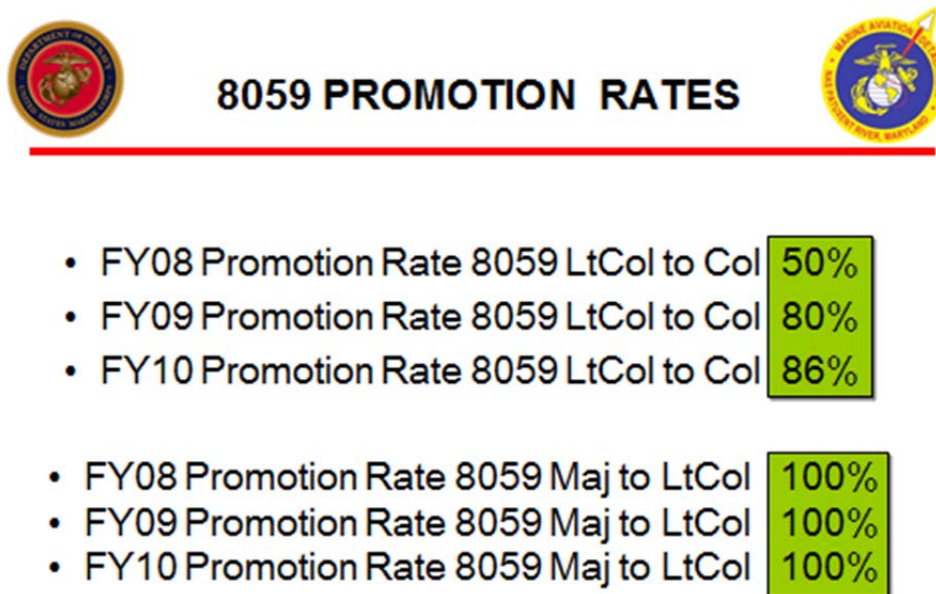


Figure 4. Rank MOS Totals by Fiscal Year

The bulk of the acquisition officer community from FY05 through FY11 was comprised of Majors with the AMOS of 8057 (4 57) and Lieutenant Colonels with the AMOS of 8057 and 8058 (5 57 and 5 58) as shown in Figure 4.

***b. 8059 Totals by Rank and FY***

The Acquisition Community has grown from its creation in 2004 to a fully staffed community in 2011. The evidence of that growth can be seen in the promotion rates of officers from Major to Lieutenant Colonel and Lieutenant Colonel to Colonel as shown in Figure 5. From 2008 through 2010, Marines with the PMOS of 8059 were promoted to Lieutenant Colonel at a rate of 100% (compared with 60-70% for other officers) and were promoted to Colonel at a rate of 50 to 86% (compared with 50% for other officers). As the Acquisition Community reaches steady state, promotion rates will more closely match rates of the general officer population.



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Figure 5. 8059 Promotion Rates for Majors and Lieutenant Colonels from FY08 through FY10 (From Expeditionary Warfare School, 2005)

The building of the 8059 community for FY05 through FY11 is displayed in Figure 6. The proportion within the community in terms of rank changes as Lieutenant Colonels outnumber Majors and Colonels combined by FY11. FY11 data shows a more balanced community much closer to steady state than FY06 through FY10.

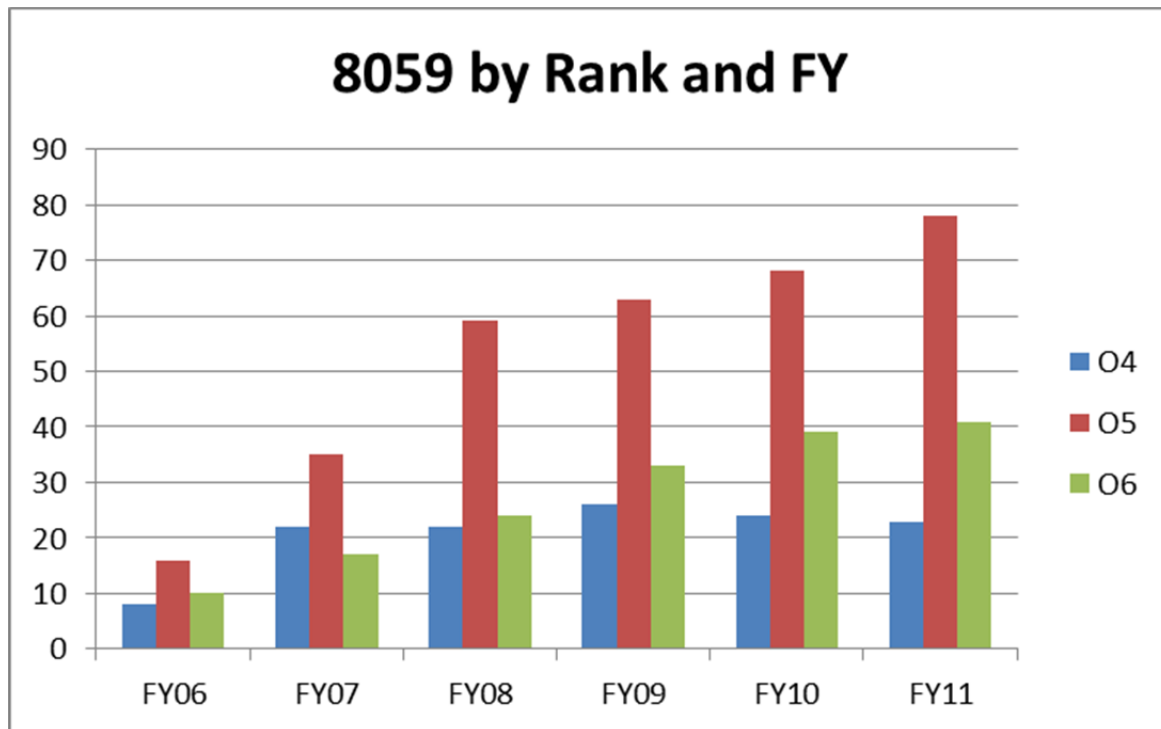


Figure 6. 8059 by Rank and FY

*c. Acquisition Community Overall Attrition by FY*

Attrition remained extremely low from FY05 through FY11 ranging from 2.3% down to less than 0.5% is shown in Figure 7. These attrition rates are quite low when compared with the general officer population during these years which saw an average of 8.3% attrition. The attrition of the Acquisition Community may be artificially low due to its infancy and the four year obligation incurred when transitioning to the 8059 PMOS. As more officers within the community satisfy the 8059 PMOS obligation and approach career milestones in years of commissioned service (20, 26, and 30 for O4, O5, and O6 respectively), the community should move closer to alignment with the general officer population, but will probably still not be as high.

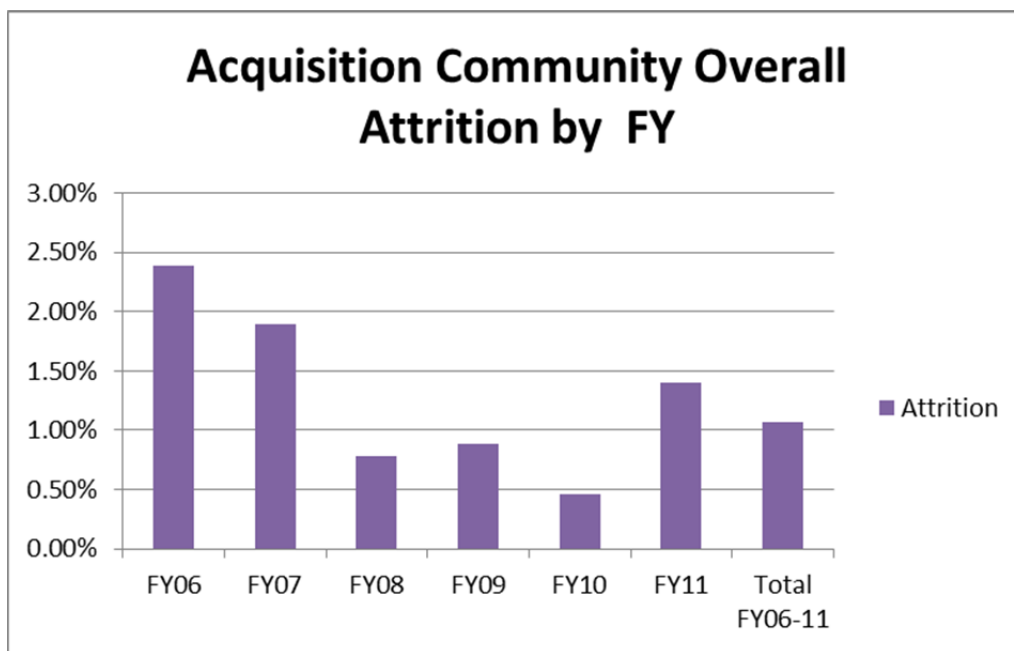


Figure 7. Acquisition Community Overall Attrition Totals by FY

## C. METHODOLOGY

### 1. Markov Model

According to Rowland and Sovereign, “Markov chains provide a systematic method of forecasting manpower supply on the basis of probabilities. The proportion of manpower changes in any particular classification is an estimate of the Markov transition probability under the assumption that the proportion of losses is constant” (1969, pp. 95-96). Using Bartholomew, Forbes, and McClean as a guide, we determine that the Marine Corps acquisition officer community can be characterized as stochastic (each officer has an *individual* probability of transition, continuation, attrition, or accession), push (officers transition due to acquired rank or qualifications rather than open billets at a higher level), and discrete (officers may only gain the PMOS of 8059 when the board meets once per year) (1991, pp. 7-8). Further, the acquisition officer community falls neatly into mutually exclusive states of rank and MOS. Given these characteristics, the Acquisition Community behavior lends itself to modeling via a markov chain.

**a. Basic Chain Assumptions**

Markov chains work under the following assumptions:

- **States:** Markov chains must consist of definable, mutually exclusive states. These states can be infinite, but for the purposes of this study, we will only consider finite states (Bartholomew, 1971, p. 14). In the Acquisition Community, the states consist of the combination of rank and MOS.
- **Markovian Property:** The probability that the system will transition to another state depends ONLY upon the current state (Bartholomew, 1971, p. 14). This means that the probability of promotion in rank, MOS, or both depends only upon the current rank MOS combination.
- **Stationary Transition Probabilities:** The markov chain should have transition probabilities which remain the stationary over time (Sales, 1971, p. 86). The predictive power of the model degrades if the transition probabilities change from one time period to the next.

**b. Notation**

Using Bartholomew et al (1991) as a guide, the notation for a basic Markov chain with  $k$  categories with transition probabilities  $p_{kk}$  and wastage (attrition)  $w$  is given (p. 96):

$$\begin{array}{ccccc} p_{11} & p_{12} & \cdots & p_{1k} & w_1 \\ p_{21} & p_{22} & \cdots & p_{2k} & w_2 \\ \vdots & \vdots & & \vdots & \vdots \\ p_{k1} & p_{k2} & \cdots & p_{kk} & w_k \end{array}$$

If we have  $k$  states, then:

$p_{ij}$  is the probability that a person in state  $i$  will transition to state  $j$  during the time step  $t$  ( $i, j = 1, 2, \dots, k$ ).  $p_i$  is the probability that the person starts in state  $i$  and remains in  $i$  during time step  $t$  (Bartholomew, 1971, p. 14).

$w_i$  is the probability that a person in state  $i$  attrites from the system during time step  $t$  (Bartholomew, 1971, p. 15).

$r_i$  is the probability that a person accesses into state  $i$  during time step  $t$  (Bartholomew, 1971, p. 15).

Each row and column sum to 1 because each individual within the system must either remain in their current state, move to another state, or leave the system altogether. Given the above statements,  $\sum_{j=1}^k p_{ij} + w_i = 1$  and  $\sum_{i=1}^k r_i = 1$  (Bartholomew, Forbes, & McClean, Statistical techniques for manpower planning, 1991, p. 97). The combination of these rows produces the transition matrix of  $P = \{p_{ij}\}$  and an attrition (wastage) vector of  $w = \{w_1, w_2, \dots, w_k\}$  (Bartholomew, Forbes, & McClean, Statistical techniques for manpower planning, 1991, p. 97).

#### **c. Stock Forecasting**

For stock and flow, we multiply the transition probability matrix  $P$  by the previous time period stock  $(t-1)$  and then add the numbers of accessions  $R$  multiplied by the accession vector  $r$  with the resulting notation of  $n(t) = n(t-1)P + R(t)r$  (Bartholomew, Forbes, & McClean, Statistical techniques for manpower planning, 1991, p. 97). Repeating this manipulation will yield the successive forecasts for subsequent years' stock.

#### **d. Other Utilities (Fundamental Matrix)**

The fundamental matrix  $S$  is constructed by taking the inverse of the transition matrix  $P_T$  subtracted from an identity matrix  $I$  of the same size given by  $S = (I - P_T)^{-1}$ . The fundamental matrix is then made up of  $s_{ij}$ 's in which  $s_{ij} = E[\text{time steps a person spends in state } j \text{ given that they started in state } i]$ . Furthermore, by using the diagonals, we can find the probability of an person who started in state  $i$  reaching state  $j$  by dividing down the diagonals given by  $P(\text{person reaches state } j \mid \text{person started in state } i) = \frac{s_{ij}}{s_{jj}}$  (Seagren C. , 2011). Essentially, the fundamental matrix of the model describes

the conditional length of time individuals remain within each state and the conditional probability of individuals ever achieving a state (Seagren, 2011).

## 2. Aggregation

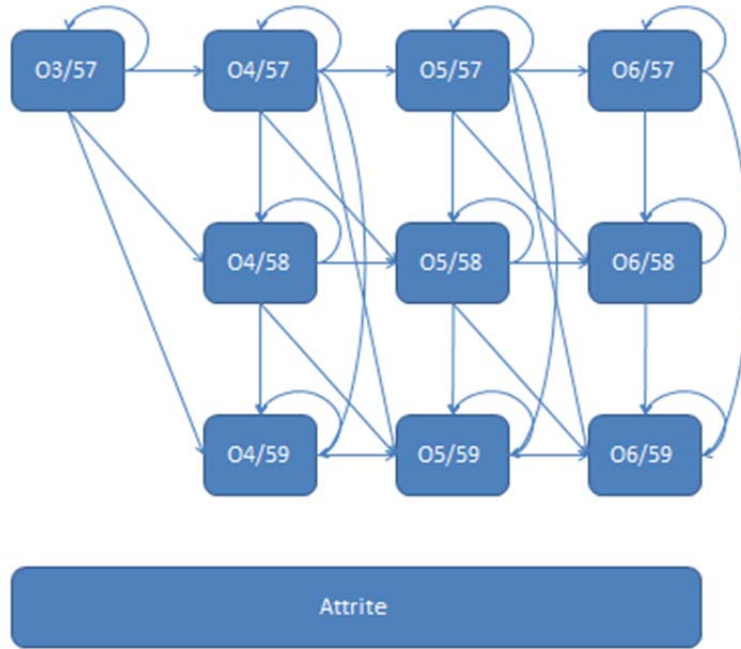


Figure 8. Acquisition Model Flows

In order to determine the transition probability matrix  $P$ , the flows between states (shown in Figure 8) for each time step are aggregated using the statistical software SAS (coding available from the author). In this case, the flows from FY05 to FY06 are delineated as FY06 with a time step of one FY and so on. With data from FY05 through FY11, six years of flows remain which are aggregated together (see Table 1).

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59	Attrition	Total
3 57	381	70	6	4							16	477
4 57		1916	79	11	54	6	4				38	2108
4 58			828	24		36	3				6	897
4 59				64			38				0	102
5 57					1737	14	1	28	1	1	25	1807
5 58						1674	23		13	4	14	1728
5 59							219			21	1	241
6 57								566	5	0	3	574
6 58									472	6	4	482
6 59										122	1	123

Table 1. Aggregated flows from FY05 through FY11

The flow for each transition possibility is then divided by the total flows from that state. For instance, the probability that an acquisition officer who began as a Captain with the AMOS of 8057 and continued within that same state is given as  $P(357|357) = 381/477 = 0.80$ . This process is conducted for each  $p_{ij}$  in the aggregated flows and in the individual time steps (see Table 2). Again, note that the rows sum to 1 because each individual must be accounted for within the system.

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59	Attr	Total
3 57	0.80	0.15	0.01	0.01							0.03	1.00
4 57		0.91	0.04	0.01	0.03	0.00	0.00				0.02	1.00
4 58			0.92	0.03		0.04	0.00				0.01	1.00
4 59				0.63			0.37				0.00	1.00
5 57					0.96	0.01	0.00	0.02	0.00	0.00	0.01	1.00
5 58						0.97	0.01		0.01	0.00	0.01	1.00
5 59							0.91			0.09	0.00	1.00
6 57								0.99	0.01	0.00	0.01	1.00
6 58									0.98	0.01	0.01	1.00
6 59										0.99	0.01	1.00

Table 2. Aggregated Transition Probabilities Matrix  $P$  for FY05 through FY11

## D. RESULTS

### 1. Validation

Using Sales graphical method for validation, we aggregate the transition probability for each  $p_{ij}$  (see Table 2). Then, we calculate the standard error for each  $p_{ij}$  using a binomial distribution as  $s.\hat{e}.\{\hat{p}_{ij}(T)\} = \left( \frac{\hat{p}_{ij}(T)\{1 - \hat{p}_{ij}(T)\}}{n_i(T)} \right)^{\frac{1}{2}}$ . Finally with the standard error, we calculate the confidence interval for each  $p_{ij}$  given as  $[\hat{p}_{ij}(T) - s.\hat{e}.\{\hat{p}_{ij}(T)\}, \hat{p}_{ij}(T) + s.\hat{e}.\{\hat{p}_{ij}(T)\}]$  (Sales, 1971, p. 88). According to Sales, “assuming that the estimators are approximately normally distributed the intervals contain the true values with a probability of approximately 0.7” (Sales, 1971, p. 88). This means that our estimated  $p_{ij}$  (the aggregate) should fall within the 70% confidence interval we build around each year’s  $p_{ij}$ . As an example, the validation from the probability of continuing in the state 4 57 given that the person started in the state 4 57 is displayed in Figure 9. The process is repeated for each  $p_{ij}$ .

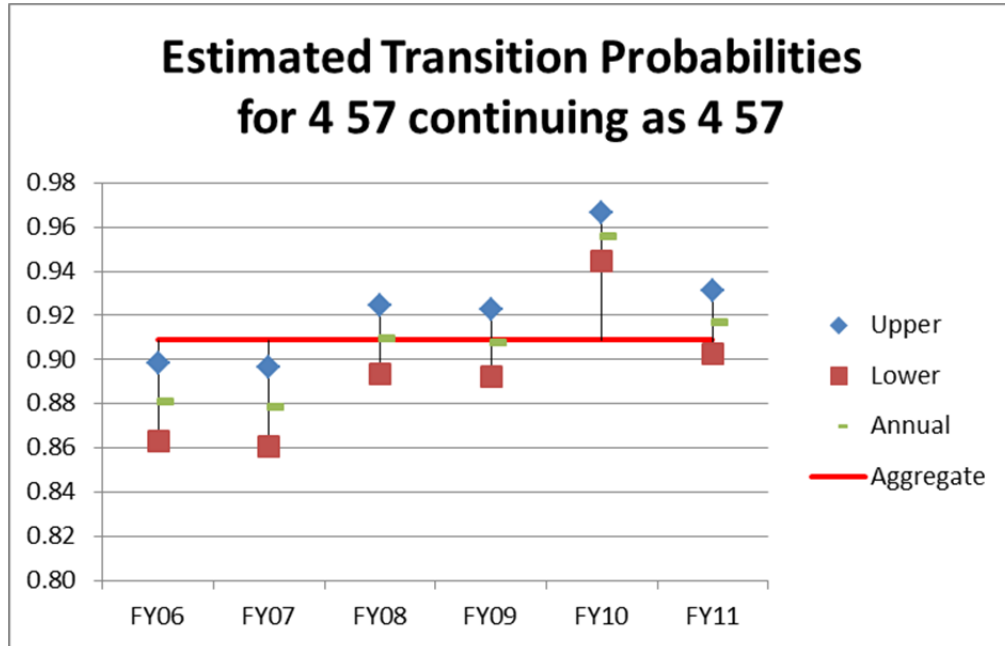


Figure 9. Estimated Transition Probabilities with 70% Confidence Interval for 4 57 continuing as 4 57

## 2. Evaluating Validation

The evaluation of the validation of the model comes from examining the proportion of estimated (aggregate) transition probabilities that fall within the established 70% confidence interval. Using 4 57 to 4 57 as an example (Figure 9), we find that of the six time steps, only 3 (50%) fall within the 70% confidence interval. Evaluating the validity of each estimated transition probability and the model as a whole is then a subjective interpretation of the proportion of estimators which fall within the given confidence intervals. The higher the proportion becomes, the higher the confidence we have in the estimator or model and vice versa. The overall model by year is shown in Table 10.

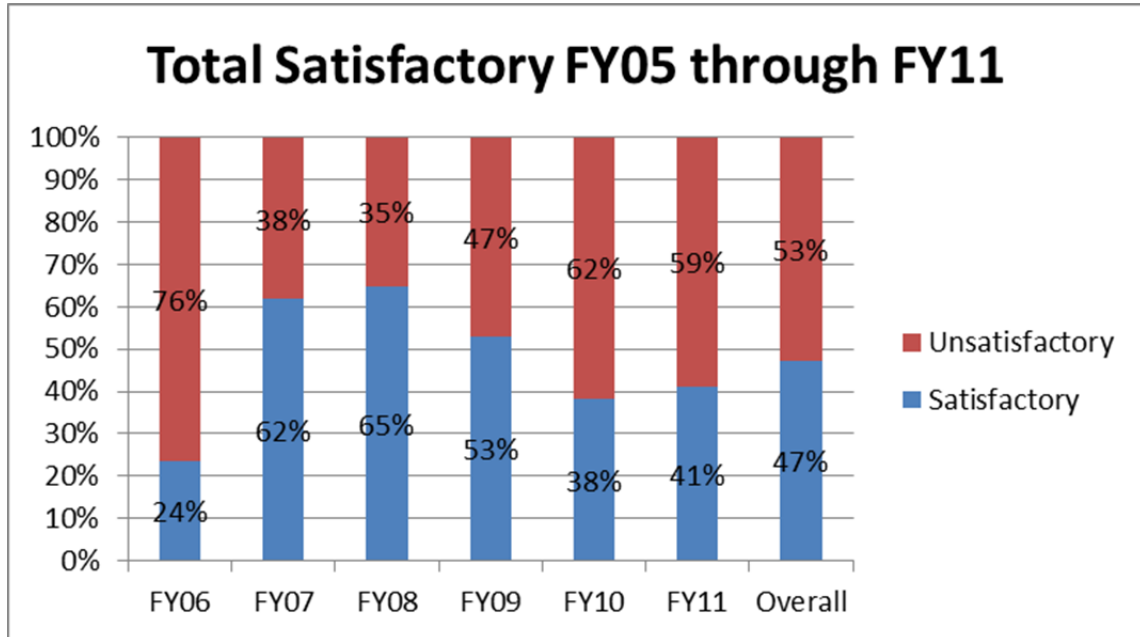


Figure 10. Overall Model Satisfactory Validation by Year FY05 through FY11

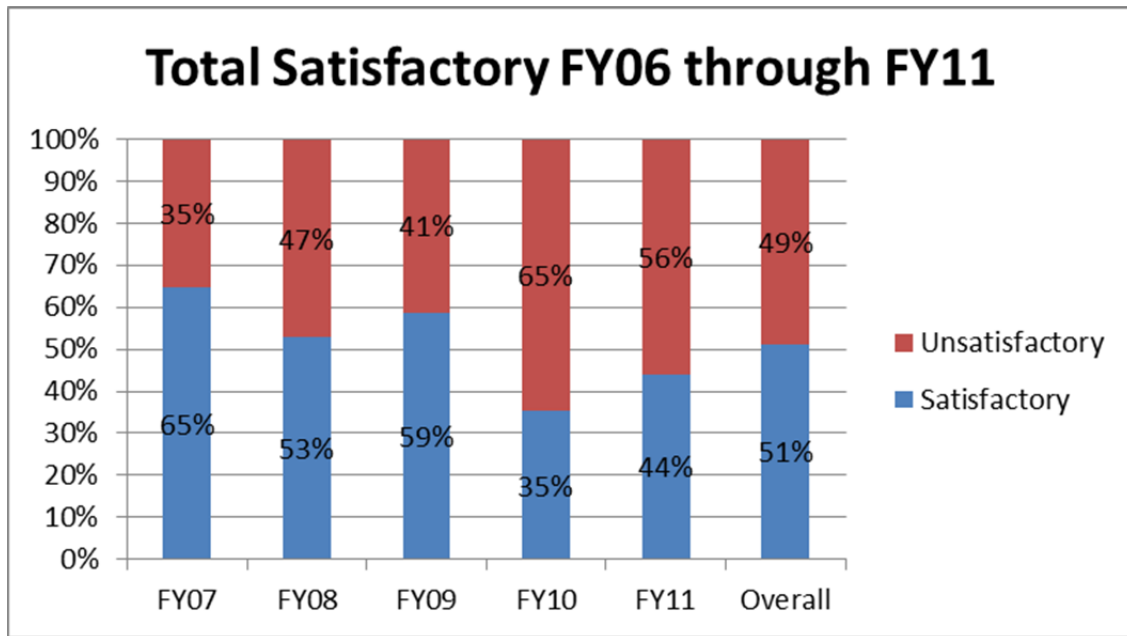


Figure 11. Overall Model Satisfactory Validation by Year FY06 through FY11

The model validation overall provides 47% satisfaction for all years FY05 through FY11 (see Figure 10). The model improves by dropping the first transition year (FY05 to FY05) as an outlier given that was the first year of the community's existence. The model using data from FY06 through FY11 provides improved validity with 51% satisfactory. For this reason, only data from FY06 through FY11 is used (Figure 11).

### 3. Stock Forecasting

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59	Attrition	Total
3 57	0.78	0.16	0.01	0.01							0.03	1.00
4 57		0.91	0.04	0.01	0.02	0.00	0.00				0.01	1.00
4 58			0.93	0.03		0.03	0.00				0.01	1.00
4 59				0.63			0.37				0.00	1.00
5 57					0.97	0.01	0.00	0.01	0.00	0.00	0.01	1.00
5 58						0.97	0.01		0.01	0.00	0.01	1.00
5 59							0.91			0.09	0.00	1.00
6 57								0.99	0.01	0.00	0.00	1.00
6 58									0.99	0.01	0.01	1.00
6 59										0.99	0.01	1.00

Table 3. Transition Probability Matrix  $P$  for FY06 through FY11

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59
Accession Vector ( $r$ )	0.24	0.38	0.11	0.05	0.05	0.06	0.07	0.01	0.01	0.02

Table 4. Accession Vector  $r$  for FY06 through FY11

Using only data from FY06 through FY11,  $P$  represents the transition probabilities matrix (Table 3). By multiplying the transition probability matrix  $P$  by the previous time period stock  $(t-1)$  and then adding the numbers of accessions  $R$  multiplied by the accession vector  $r$ , we can forecast inventory levels for future FYs. Table 5 and Figure 12 represent a stock forecast when the number of accessions into the system remains fixed at 75 per year.

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59	Total
FY11	88	376	182	23	312	308	78	105	87	41	1600
FY12	87	386	193	27	314	314	89	108	90	51	1658
FY13	86	395	203	29	315	321	101	111	93	61	1716
FY14	86	403	214	31	317	328	113	114	95	73	1773

Table 5. Stock Forecast for FY12 through FY14 from  $n(t) = n(t-1)P + R(t)r$

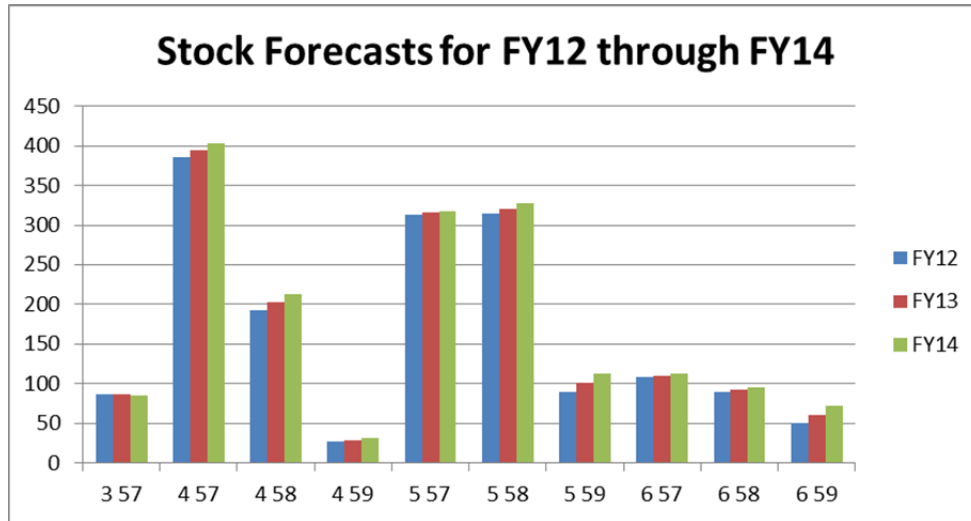


Figure 12. Stock Forecast for FY12 through FY14

Forecasting using this model can provide insight into policy changes within the Acquisition Community. As an example, reducing the number of billets for 8057s would reduce the number 8057 accessions at all ranks. By adjusting the number of accessions into the model to represent this policy, the model will forecast the shape and size of the community in the following years. Adjusting the accession inputs or the transition probabilities within the model provides a variety of policy evaluation tools for manpower planners.

#### 4. Other Utilities (Fundamental Matrix)

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59
3 57	4.58	8.47	5.54	0.70	5.43	9.77	4.40	4.33	7.81	57.12
4 57		11.64	6.34	0.70	7.47	11.79	4.71	5.96	9.97	63.12
4 58			13.67	1.08		17.61	6.93		8.26	86.26
4 59				2.68			10.95			117.41
5 57					30.06	9.67	1.39	23.99	22.41	40.06
5 58						37.18	4.49		17.44	73.40
5 59							10.95			117.41
6 57								70.57	48.57	43.93
6 58									68.00	61.50
6 59										123.00

Table 6. Fundamental Matrix  $S = (I - P_T)^{-1}$

The fundamental matrix displayed in Table 6 provides useful information for evaluating the Acquisition Community. The second column and first row of Table 6 reveal that a Major with the AMOS of 8057 who started out as a Captain with the AMOS of 8057 will spend 8.47 years as a Major with the AMOS of 8057. Additionally, Table 7 reveals various conditional probabilities derived from the diagonals. In this model, a Captain with the AMOS of 8057 has a 40.1% probability of reaching Lieutenant Colonel with the PMOS of 8059. Both of these types of data describe to manpower planners how long individual remain at various states within the Acquisition Community as well as their probability of ever attaining differing states within the community.

$P(5\ 59 3\ 57) = 4.40 / 10.95 = 40.1\%$
$P(5\ 59 4\ 57) = 4.71 / 10.95 = 43.0\%$
$P(5\ 59 5\ 57) = 1.39 / 10.95 = 12.7\%$
$P(6\ 59 3\ 57) = 57.12 / 123.00 = 46.4\%$
$P(6\ 59 4\ 57) = 63.12 / 123.00 = 51.3\%$
$P(6\ 59 5\ 57) = 40.06 / 123.00 = 32.6\%$

Table 7. Conditional Probabilities of Attain Given States

## E. LIMITATIONS

The small size and relative infancy of the community call into question the usefulness of the data, and therefore the results may be less than optimal. As a newer community, the first few years of data may not be stationary because they represent the building of the community and not steady state operation. The small sample size further reduces the effectiveness of the model due the added variance which would not be present in a model using a data from a larger population such as Marine Officers as a whole. A glance at the fundamental matrix of the model shows spurious numbers (such as a Colonel spending 123 years as Colonel given that they started out as a Colonel). As a result of these limitations, further years of data need to be collected in order to further validate the stock forecasts and for the fundamental matrix portion of the model to be useful.

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## **V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS**

### **A. SUMMARY**

The Marine Corps Acquisition Community represents only a small portion of the Marine officer force structure, and yet exerts a disproportionate amount of influence over the future capabilities of the Marine Corps. Currently, no manpower planning tools exist for force shaping of the Acquisition Community. This research addresses that shortfall.

### **B. CONCLUSIONS AND RECOMMENDATIONS**

#### **1. Would a Markov Model Provide an Accurate Forecasting Tool for Inventory Levels of the Marine Corps Acquisition Community?**

##### ***a. Conclusions***

Due to data limitations, forecasting beyond one year of stocks or using the other utilities of the fundamental matrix portion of the model are currently suboptimal. The data used to create the model represents the building of the community rather than the steady state of the established community. The behavior exhibited by the Acquisition Community over the period examined will change as the community levels out towards steady state.

The forecasts and predictions of the model should be weighed by the workforce experience and analysis of manpower planners and Acquisition Community leadership. Due to the current low validation of the model due to non-stationary transition probabilities, this model is currently suboptimal for use in force structure policy decision making. However, the dearth of data and decision making tools mean that this model is the only empirical tool currently available for aiding in future policy decisions.

##### ***b. Recommendations***

Marine Corps acquisition officer managers should continue to collect data and monitor the model's validity. As the acquisition workforce matures towards steady state, the additional years of data should prove the model developed by this research is valid.

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## APPENDIX. SUMMARY STATISTICS

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59
FY05	74	327	118	0	304	278	0	80	74	0
FY06	80	329	126	8	306	281	16	91	74	10
FY07	80	341	147	22	297	284	35	98	79	17
FY08	73	367	153	22	299	288	59	98	84	24
FY09	86	359	176	26	296	294	63	103	84	33
FY10	84	385	177	24	305	303	68	104	87	39
FY11	88	376	182	23	312	308	78	105	87	41

Table 8. Rank MOS Totals by FY.

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59
FY06	2	13	1	0	8	4	0	1	1	0
FY07	3	7	2	0	8	4	0	1	0	0
FY08	2	3	0	0	4	2	0	0	0	0
FY09	1	2	0	0	4	4	0	0	2	0
FY10	3	1	2	0	0	0	1	0	0	0
FY11	5	12	1	0	1	0	0	1	1	1

Table 9. Attrition by Rank MOS and FY.

	3 57	4 57	4 58	4 59	5 57	5 58	5 59	6 57	6 58	6 59
FY06	14	35	12	7	6	7	7	1	1	6
FY07	20	36	16	6	2	8	8	3	2	3
FY08	17	38	2	3	4	5	9	0	0	0
FY09	24	20	11	4	2	2	1	1	0	1
FY10	15	28	5	0	6	4	4	0	1	0
FY11	20	14	2	2	4	2	2	0	0	0

Table 10. Accession by Rank MOS and FY

	O4	O5	O6
FY05	0	0	0
FY06	8	16	10
FY07	22	35	17
FY08	22	59	24
FY09	26	63	33
FY10	24	68	39
FY11	23	78	41

Table 11. 8059s by Rank and FY

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